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Extreme Ultraviolet
Tunable XUV
Gamma ray laser

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This contract supported a critical phase of an ongoing project having the objective of determining the feasibility and means of realizing a gamma-ray laser. Previous work had served to establish that a gamma-ray laser is feasible if a certain combination of elementary properties can be found in a real nuclear material. Traditional technology could not support the evaluation of these laser-like properties of nuclei and new methodologies had to

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20. Abstract

be developed. Described here are highly significant successes in the development and demonstration of prototypes of two new devices needed for the screening of candidate laser materials in a realistic time frame, a flash x-ray device for pumping test materials and a Nuclear Raman Spectrometer to facilitate the search for certain arrangements of nuclear energy levels.

FINAL TECHNICAL REPORT

for the period

16 July 1985 through 15 July 1986

for

Office of Naval Research
Contact N00014-85-K-0478
Task No. NR SDRE-102

EXPANSION OF RESEARCH ON THE TUNING AND STIMULATION OF NUCLEAR RADIATION

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TABLE OF CONTENTS

INTRODUCTION

The universal concerns of those aspiring to develop a new type of high-power pulsed laser are to maximize the storage time of the pump energy and to minimize the bandwidth of the laser transition. Successes in either direction are generally rewarded by lessened demands upon both the peak level of input power and total fluence needed in the pump source to achieve threshold in the laser medium. By definition, a gamma-ray laser must draw its energy from nuclear excitation and so there exists the unique opportunity to exploit the Mossbauer effect to insure that the minimum bandwidth possible for the laser transition is actually achieved. Provided the macroscopic host in which the emitting nuclei are diluted is sufficiently rigid and provided temperatures are sufficiently reduced, nuclear transitions at energies in the range from 1-100 keV can occur with widths corresponding to the natural lifetimes of the levels. Over the past six years, our research group has described[1-14] several viable means through which this excitation energy might be coupled at will to the radiation fields while maintaining the natural Mossbauer width. In such cases the cross section for stimulated emission could reach 10^{-17} cm^2, ten times more favorable than the value for the stimulation of 1.06 μm from Nd^{3+} in YAG.

At the nuclear level the storage of excitation energies in the Mossbauer range can approach tera-Joules (10^{12} J) per liter for thousands of years. The stimulated release of this energy would occur at the rate at which resonant electromagnetic radiation passed through the laser medium and could lead to output powers as great as 3×10^{21} Watts/liter. This is an

astronomical level of intensity and has not been approached to within five orders of magnitude on earth by any means previously. The peak power from a one liter device would represent 0.03% of the total power output from the sun. At this level a relatively small laser rod of 5 mm in diameter and 1 cm long would emit a pulse of power comparable in amplitude to the total power developed by a 100 megaton nuclear device at the peak of its burn. Of course the output from the 100 megaton detonation would persist for a much longer duration, but with the laser the same total power would be delivered in a narrow output beam.

Unfortunately, the quest for a gamma ray laser has been one of the longest unfruitful efforts in the field of laser science. Virtually all of the sustained pioneering work was done by Baldwin and Solem's groups in the US and by Gol'danskii's in the USSR and focused upon the single photon, brute force approach to pumping. Their work dealt extensively with concepts involving the use of a neutron flux for pumping the laser medium, either in real-time or as a preparatory step to be followed by a rapid separation of isotopes within their natural lifetimes. All proposals were concluded to require infeasibly high levels of particle fluxes to pump the inversions, exceeding even those available from nuclear explosions, and to require neutron moderators having virtually infinite thermal capacities. By 1980 all conceivable variants of the single photon approach had been characterized as hopeless. In 1981 this "traditional" approach to a gamma ray laser was virtually abandoned with Baldwin's publication of the monumental review[15] of all classical efforts.

The involvement of our UTD Center for Quantum Electronics

dates back to 1978 and can be conveniently divided into three periods of accomplishments. First was an NSF sponsored period of international theoretical effort from 1978 to 1981. It arose from a long program of previous activity focused upon fundamental interactions of coherent radiation with matter that had been conducted within NSF's International Cooperative Science Program. Concerned at first with the problem of the correct gauge and basis sets to use in describing multiphoton process, we began to consider the impact of the work upon areas other than the usual atomic and molecular. As a result, the modernized concept of coherent pumping with optical radiation was introduced in a sequence of papers[1-7] concerned with nonlinear processes mediated by virtual states of nuclear excitation and included the stimulated anti-Stokes scattering of intense but conventional laser radiation.[6] The theoretical treatment served to estimate matrix elements for a new class of two-photon Mossbauer transitions making possible, in principle, the frequency upconversion of optical laser photons to gamma ray energies.

In 1981 the implications of this theoretical renaissance to the prospects for a gamma ray laser based on several variants of upconversion were reviewed in an article[8] appearing the following year. If strengthened by recent infusions of dressed state theory,[16,17] that article still provides the most convenient review of the basic concepts and requirements for a viable gamma ray laser scheme.

The second phase of our γ-ray laser program at UTD began in 1981 with the initiation of a modest effort supported by ONR that

was aimed at providing some experimental verification of the theoretical models. Successful beyond any reasonable expectation, it produced a small but important group of experiments that have been recently reported.[9,11-13] These experiments to date have confirmed:

1) That the matrix elements used in the previous research phase to obtain the favorable estimates of the threshold for laser output *were correctly estimated;*
2) That extremely large ferromagnetic enhancements of the effective powers applied in the coherent pumping scheme can be obtained;
3) That enhancements may also result from the modulation of the polarization of ferroelectric media in which coherently pumped nuclei could be diluted.

The conclusion from these experiments is *that the gamma-ray laser is definitely feasible if a sufficiently ideal isotope exists in reality.* This is the single most critical issue to the development of a gamma-ray laser--the identity of the most nearly ideal candidate for upconversion.

Despite the many applications of beautiful and involved techniques of nuclear spectroscopy, the current data base is inadequate in both coverage and resolution either to answer the question of whether an acceptable isotope exists or to guide in the selection of a possible candidate medium for a gamma-ray laser. Two new techniques for the measurement of nuclear properties with laser-grade precision resulted from the second phase of our research into the feasibility of a gamma-ray laser.

The contract supporting the achievements being currently

reported initiated a third phase of the project. The objective of this phase was to develop and to demonstrate prototypes of the hardware needed to instrument the two new measurement techniques that will be essential for the screening of candidate materials for a gamma-ray laser. Reported here will be the construction and evaluation of a flash x-ray device for pumping test materials and a Nuclear Raman Spectrometer to facilitate the search for certain necessary arrangements of nuclear levels.

TECHNICAL BACKGROUND

By involving two distinct steps, the schemes we have proposed for pumping a gamma-ray laser avoid the severe relationships between storage times and spontaneous powers wasted at threshold that were imposed on the single-step processes.[15] Replacement power that is required falls within a technically accessible range avoiding damage to the laser medium.

These two-step, upconversion processes for optically pumping nuclear reactions can be divided into two categories that correspond to the type of pumping employed: coherent and incoherent, as shown in Fig. 1. The critical concept here is that either transfers the stored population to a state at the head of a cascade leading to the upper laser level. To be effective the pumping processes cannot transfer too many quanta of angular momenta from the fields and the cascade provides a mechanism for further changes that may be necessary to reach the laser levels. Then the ultimate viability of these pump schemes will depend upon: (1) spectroscopic studies locating a suitable configuration of nuclear energy levels, and (2) "kinetic" studies

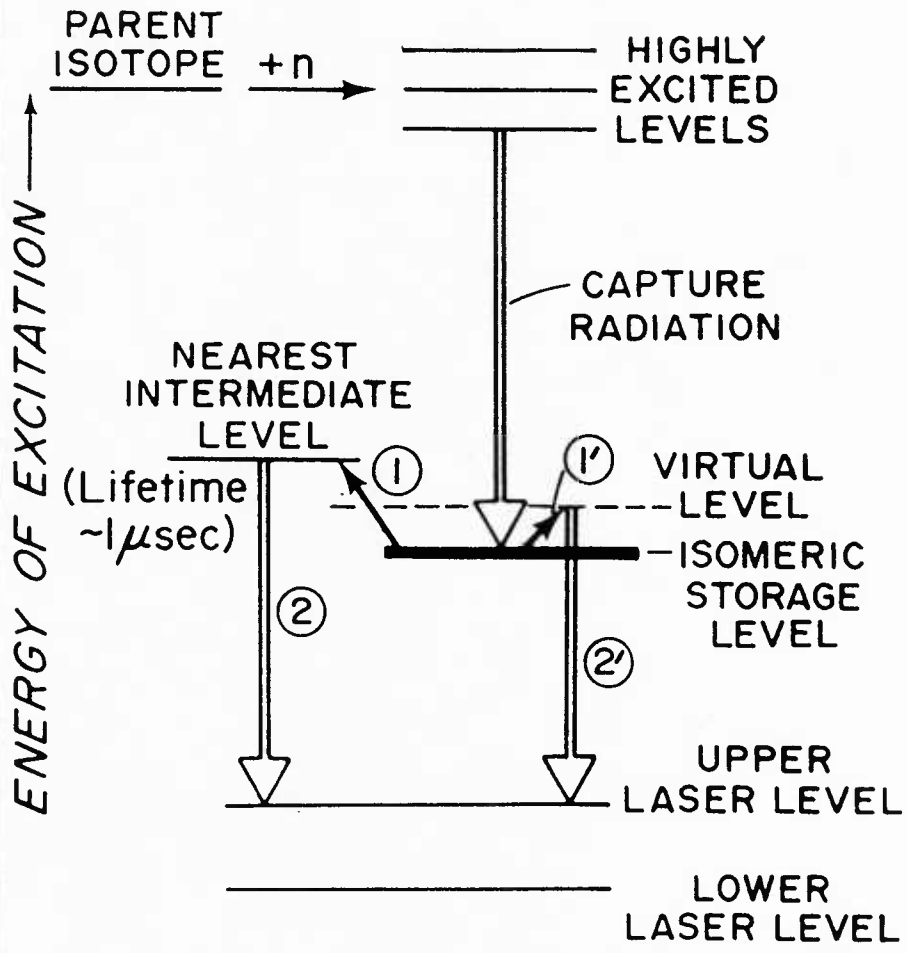


Figure 1

Schematic diagram showing the energetically excited levels of a typical nucleus of interest to the development of a gamma-ray laser. Lifetimes of the stored energies in the isomeric level produced by the initial capture can range from days to hundreds of years. The first phase of the two-step process for the stimulated release of the stored energy is shown in the figure by the solid arrows. Both correspond to the use of longer wavelength radiation to lift a nucleus from the storage level to a higher level of excitation that has a much shorter lifetime. The arrow marked (1) illustrates the incoherent pumping of the storage level through the absorption of an x-ray that is resonant with the energy separation between the storage level and the next higher level of proper symmetry. The arrow marked (1') represents the alternative process of coherent pumping through the non-resonant absorption of a photon from the radiation field in order to create a virtual or dressed state of excitation shown by the dashed level in the figure. In either case the gamma-ray output ultimately results from the upper laser level populated by a cascade occurring as a second step, as shown in the figure by either of the double arrows, (2) and (2').

providing an efficient path of cascading from the intermediate or dressed state to the upper laser level.

Both the coherent and incoherent schemes for pumping a gamma-ray laser make stringent demands upon the arrangement of nuclear energy levels in the potential laser material. Both also depend upon the successful arrangement of an input source of radiation either to mix the properties of the storage level with those of some other state to release the metastability or to simply transfer the populations from the storage level to the other state.

For the examination of the nuclear properties we introduced the techniques of Modulated Nuclear Radiation (MNR). This methodology is the nuclear analog of the optical double resonance studies which yielded much of the laser-grade database upon which rest the newer visible and UV lasers. A database of comparable quality for nuclear "kinetics" will be required for the screening of the candidate materials, and this will require a great amount of input radiation into implementations of the MNR process. Essential to the success of this technique is the accessibility of a source of pulses of x-rays of nanoseconds duration that can emit a total of 10^{16}keV/keV of linewidth in a reasonably brief working period. Either laser plasmas or large e-beam machines can do this in a single shot, each of which requires about an hour of laboratory time to prepare; but costs are very high. As a result, none of these traditional light sources for the subAngstrom region could be used to complete an evaluation of the 29 most attractive materials before the turn of the century. In the following section we report recent successes with a prototype

flash x-ray device producing 35 mW of average power from 10 nsec pulses at energies near 8 keV, a level of performance approaching that of a large synchrotron light source. University of Texas System attorneys have considered this device to be patentable, and appropriate actions have been taken.

To facilitate the search for the scattering states energetically near isomeric levels, we had described[12] a new technique of Nuclear Raman Spectroscopy that now promises to extend both the resolution and the tuning range available for high resolution nuclear spectroscopy of the type needed in the search for potentially resonant intermediate states needed for applications of the dressing process.

The physical effect upon which this technique depends is that new transition frequencies are generated at the sums and differences between the frequency of the gamma transition and those of an integral number of photons dressing the nuclear states. By varying the frequency of the mixing radiation the energy of the sum frequency line can be swept, just as in the analogous processes implemented in the optical range and this provides the bases for the Nuclear Raman Spectroscopy (NRS) technique. It could be used to conduct Mossbauer spectroscopy with much higher resolution than previously achieved. This would be possible because no mechanical tuning needs to be used. In case microwave or infrared photons were used, the tuning range of Mossbauer spectroscopy would be dramatically increased. Viability of this NRS technique has now been fully demonstrated up to radiofrequencies. The most recent results are described in the

following section.

ACHIEVEMENTS

A Flash X-Ray Source of Intense Nanosecond Pulses Produced at High Repetition Rates

Central to the problem of using our MNR technique to evaluate candidate materials for a γ-ray laser is the accessibility to a source of pulsed X-rays that can emit at least 10^{16} keV/keV in a reasonably brief working period. We mentioned above that laser plasmas can do this in a single shot, each of which requires about an hour of laboratory time to prepare.

This section reports one of the achievements[18] realized in our Center for Quantum Electronics at UTD from this contract work. We have succeeded in demonstrating a compact flash X-ray device producing 35 mW of average power isotropically from 6 nsec pulses at energies near 8 keV. At this level we produce a photon flux in the K-lines that is only one order of magnitude lower than the design objective of the Advanced (Synchrotron) Light Source (ALS). In less than a minute our device delivers an integrated fluence comparable to that obtained in a similar line from a multi-kiloJoule, laser plasma shot. Of course, each of the larger devices has its unique advantages, more collimated beams from the synchrotrons and richer line spectra from the laser plasmas; but unless those capabilities are essential to a particular application, the laboratory scale system we report here may offer attractive support for many experiments in other applications, as well. Since it can be scaled to much higher energy K-lines and much larger sizes, it represents a proof-of-feasibility of the large scale device,

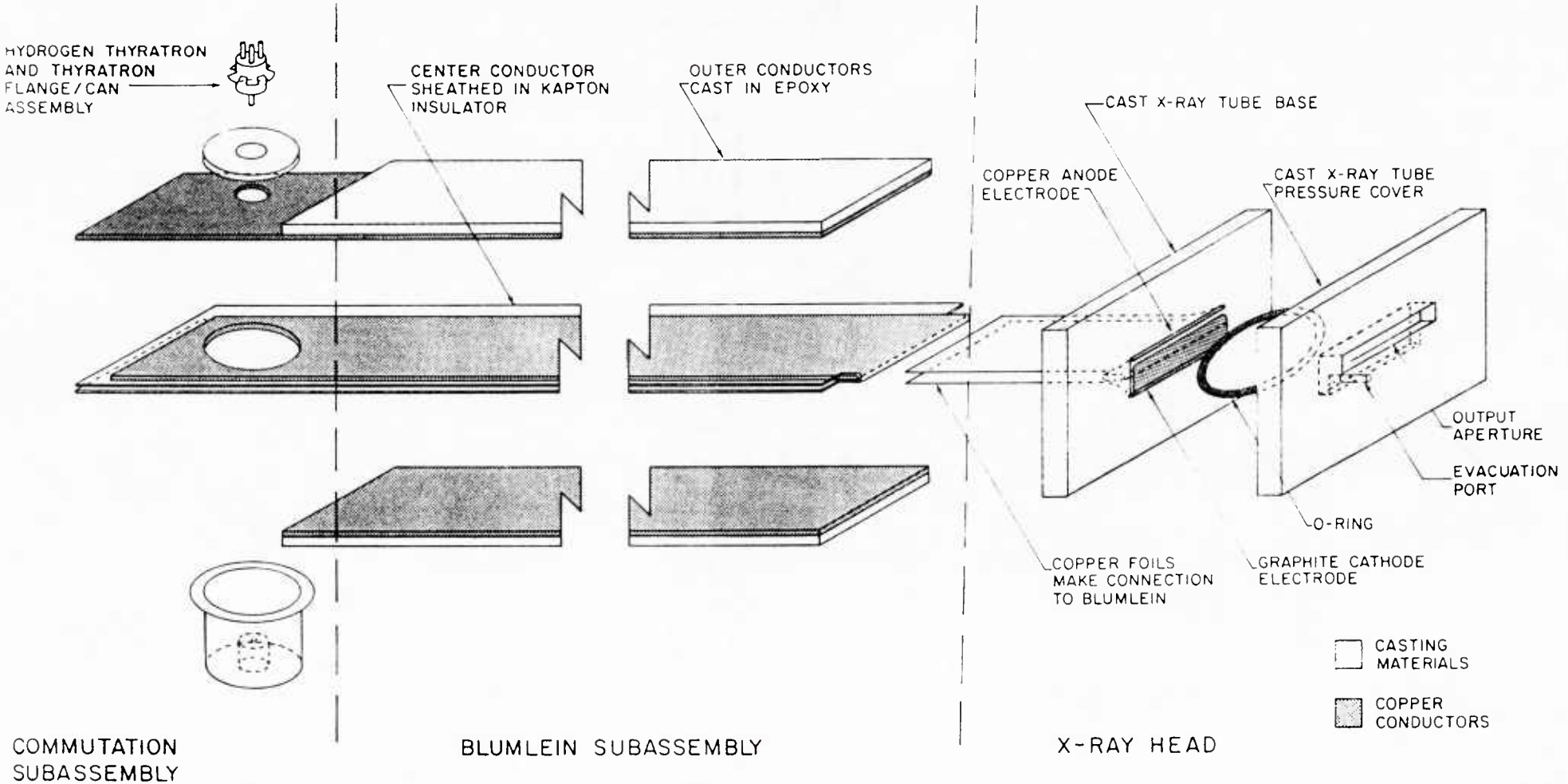


Figure 2

Schematic drawing of the high repetition rate, flash x-ray device characterized in this work.

needed for the irradiation of candidate laser materials that must be pumped at energies beyond those available from laser plasmas.

As shown in Fig. 2, this first flash x-ray device consisted of three critical subassemblies: 1) a low impedance x-ray tube, 2) a Blumlein power source and 3) a commutation system capable of operation at high repetition rates. The latter two components differed little from drivers we had developed for short pulse nitrogen ion lasers.[19] For the present application the Blumlein was constructed from massive copper plates, potted with epoxy on outer surfaces to reduce corona and separated by layered Kapton (polyimide) dielectrics of 0.635 mm total thickness. The line impedance and transit times were calculated to be of the order of 1.5Ω and 5.3 nsec, respectively. Capacitances of the switched and storage sides of the line were measured to be 3.5 and 3.2 nF, respectively. In operation the middle conductor was charged to a positive high voltage which could be varied to 25 KV and commutation was effected by an EG&G 3202 hydrogen thyratron mounted in a grounded grid configuration. The average available input power was sufficient to support operation to a 100 Hz repetition rate.

With emphasis on obtaining a singularly low inductance input to electrodes designed to give a filamentary source of radiation, the x-ray tube was constructed from cast materials, selected to minimize erosion and maximize heat transfer. Copper foil strips 0.05 mm thick and 10 cm wide were fastened to the electrode mounts and then passed through the cast material forming the base of the x-ray head before it hardened. After emerging from the base, the foils were joined to the outermost copper plates of the Blumlein.

In this way any transverse constriction of the path of the discharge current between the Blumlein and the electrodes was avoided.

The anode was simply a rod of copper partially buried in the cast material forming the base while the cathode was demountable. It consisted of a strip of 0.381 mm thick graphite further ground with a blade-like edge 10 cm wide and separated from the anode by a variable distance chosen to optimize performance. The electrical length of the strip was selected to give a resistance that was comparable but below the line impedance in order to assist in damping the ringing of the discharge current at times subsequent to the initial pulse which produced the x-rays.

The discharge space was enclosed by a pressure shell, also fabricated from cast materials with an integral window of 0.076 mm thick Kapton plastic film. The window aperture was covered with a graphite plate 0.127 mm thick to eliminate the emission of visible and UV light. Even with the cast construction and ready access to internal electrode spacings, operating pressures below 3.0 mTorr were routinely maintained with a small mechanical pump.

Precise measurements of time-resolved voltages and currents were rendered difficult by the extremely low impedance of the Blumlein and by the commutation of the thyratron in a grounded grid configuration on this particular decade of time scales, 1-10 nsec. Operation generally produced the switching waveforms expected of such Blumleins[19] with the observation that the slower commutation of the thyratron prevented a full doubling of the applied d.c. voltage. The discharge seemed to develop at a value of voltage across the x-ray tube that was roughly 50% larger than the original charge voltage of the Blumlein.

Outputs were detected with a block of fast scintillator plastic equivalent to NE114 with a nominal 7.0 nsec decay time. The resulting light output was measured with a faster photomultiplier with 1.5 nsec resolution and recorded with a Tektronix 7912AD transient digitizer. Numerical deconvolution was subsequently employed to remove these instrumental time constants. The resulting data is shown in the inset to Fig. 3 to have a temporal width (FWHM) of about 10 nsec.

Measurements of absolute intensities were made by comparing the time integrated fluorescence from the plastic detector when illuminated with geometrically attenuated x-rays from the flash source directly with the level of excitation produced by a radioactive source of known characteristics. This technique was used to determine the dependence of the total energies in the x-ray pulses as functions of the important experimental variables. Results are shown in Fig. 3 and suggest a rather surprisingly weak dependence of the output on anode-cathode separation over a substantial range of the smallest gaps. Moreover, an examination of the pulse durations at the different separations showed no variation that could be detected within the limits of resolution permitted by the deconvolution noise apparent in the inset to Fig. 3.

Under single pulse conditions the x-ray fluence delivered to an external target could be visually examined for uniformity by allowing it to fall upon a fluoroscopy screen of the type used in radiography. A uniform pattern, sharply delineated by the edges of the output aperture could be readily seen to result from

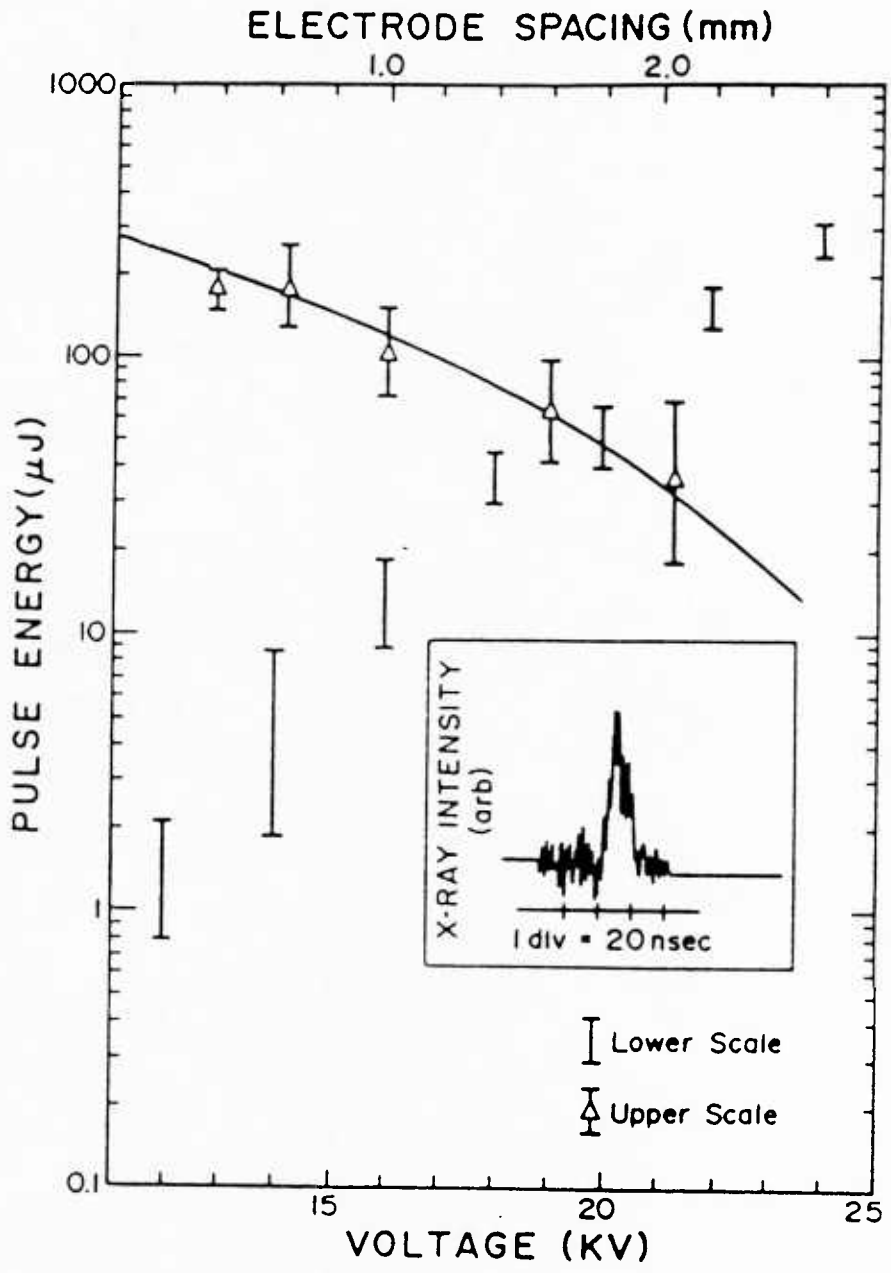


Figure 3

Total pulse energies emitted near 1.5 A under single shot conditions (2Hz) as functions of the critical experimental parameters: charge voltage and electrode spacing. While obtaining the variations shown, the other parameter was fixed at 0.127 mm spacing and 24 kV, respectively. Shown in the inset is the time resolved intensity from a typical pulse at 24 kV and 0.127 mm gap.

the great majority of discharges. At higher repetition rates the x-ray pulse energies were found to *increase* markedly, in direct contrast to the behavior generally observed in other applications when such Blumleins were used for the deposition of energy into large volumes of gaseous laser media. Figure 4 shows that the resulting dependence of the average x-ray power emitted upon repetition rate seems to be greater than linear because of this enhancement of pulse energies at the higher values.

Attenuations measured with a combination of K-edge filters and known thicknesses of aluminum foil indicated that at least 25% of the total x-ray energy lay in the Cu K_α lines, in agreement with previous observations and expectations.[20,21] If it is assumed that these lines have their customary width of around 6eV, best values of output energy correspond to about 4.7×10^{13} keV/keV when expressed in terms customary for reporting laser plasma yields. *Thus, in less than a minute of experimental time at 100 Hz repetition, over 2×10^{17} keV/keV could be emitted.* This would exceed the dose available from a shot of a large laser plasma system at these X-ray wavelengths corresponding to 8 keV.

Nuclear Raman Spectrometer

During this contract period a fully integrated Nuclear Raman Spectrometer was designed, constructed and has now begun to operate. Built from an Apple computer and a Wavetek frequency synthesizer it provides for the conduct of swept frequency spectroscopy of nuclear levels without the need to employ any mechanical effects for tuning that are required in conventional implementations of Mossbauer spectroscopy. The successes of the

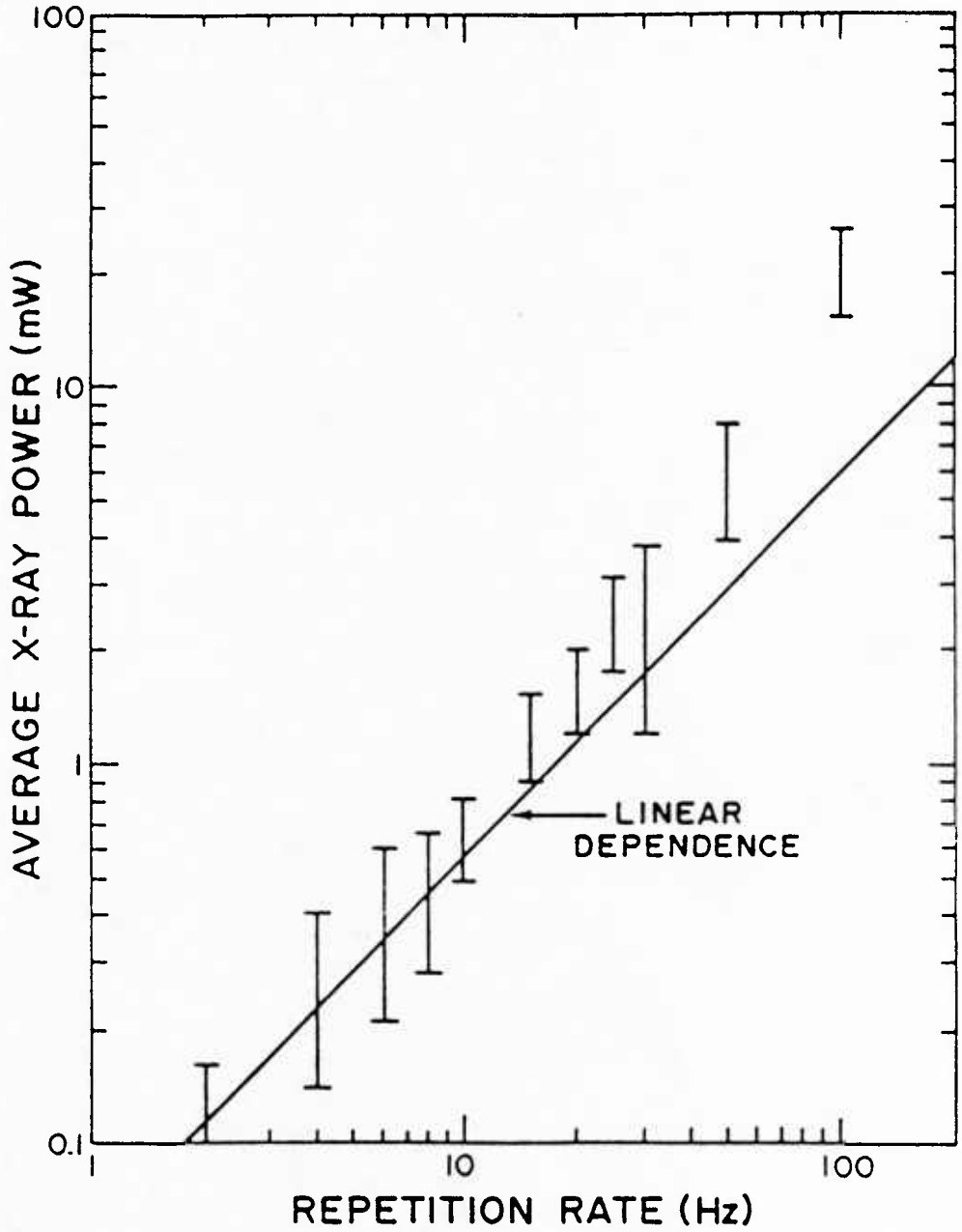


Figure 4

Average powers emitted as X-rays near 1.5 A as a function of the repetition rate for a charge voltage of 20 kV. The linear approximation corresponds to the emission of a pulse energy independent of repetition rate.

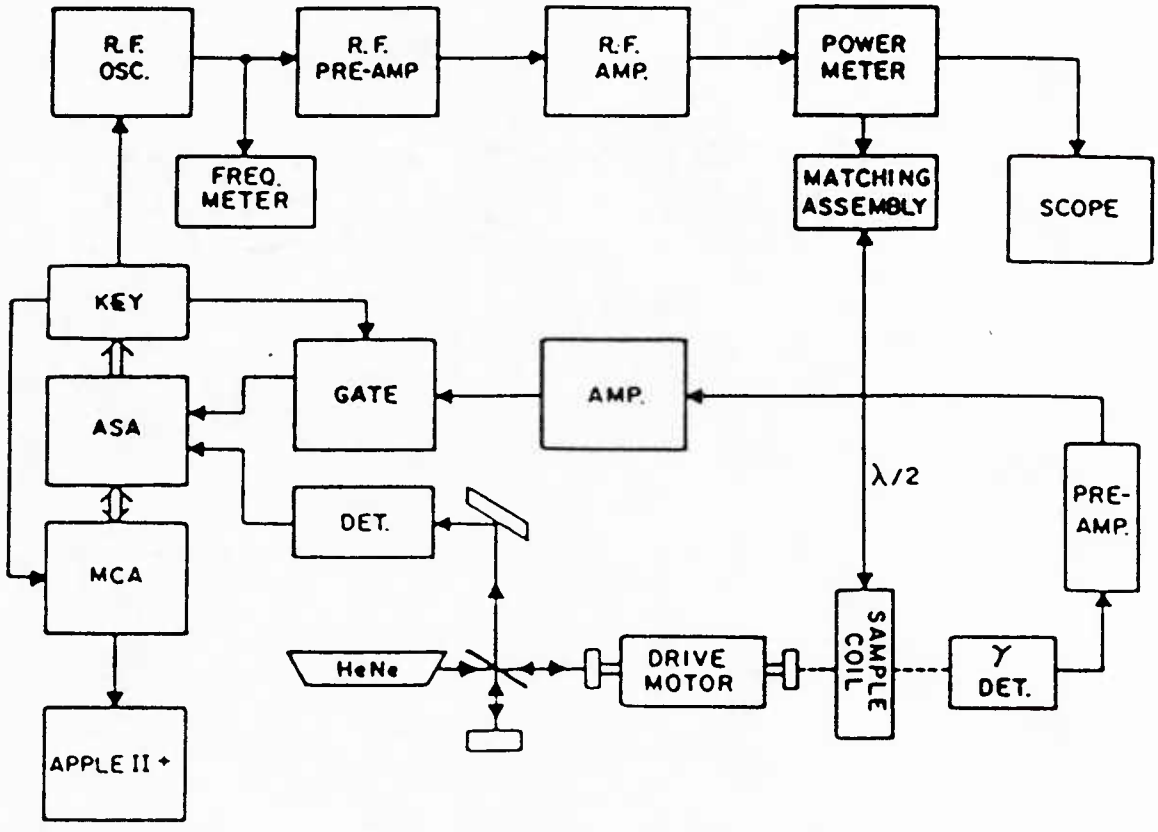


Figure 5

Schematic representation of the experimental apparatus for demonstrating the mixing of nuclear states in ^{57}Fe.

new NRS technique for nuclear spectroscopy indicate that a much higher resolution, by perhaps six orders of magnitude, can be achieved through a further upgrade of the apparatus. If the range of tunability does extend to the ferromagnetic spin resonance (FSR) frequency, then it will be possible to construct a swept frequency device capable of continuously tuning over a range of 10^{11} linewidths, an enormous improvement in the state-of-the-art of nuclear spectroscopy.

Construction details and operation of a prototype NRS system were reported in the literature[12] earlier this year. That device is shown schematically in Fig. 5. It was first intended to be the nuclear analog of a spectrophotometer in which the dispersive element is replaced with a constant acceleration motor which moves a narrow line source of gamma radiation in order to sweep the wavelength by the resulting Doppler shift. The radio-frequency power was applied to a coil containing the absorption foil. It was pulsed for a duration equal to the time required for the full sweep of the range of velocities being examined. The output from a proportional counter monitoring the transmitted γ intensity was gated into a multichannel scalar only during those times.

The absorption spectrum of ground state ^{57}Fe nuclei has long been considered a benchmark for techniques of Mossbauer spectroscopy. In pure polycrystalline iron foil the magnitude of the bulk magnetization is the same at all nuclei but varies widely in direction for nuclei in different magnetic domains. As a result, the standard 14.4 keV transition to the first excited state is split by the hyperfine energies resulting from different

orientations of the spins of the states with respect to the local magnetization vector. Figure 6 shows typical data with the six allowed transitions being identified by the quantum numbers for spin projection with the order for the M_J being ground state followed by excited state.

Also shown in Fig. 6 are the sidebands to these six basic transitions produced by dressing the nuclear states with radiofrequency (rf) photons from the applied field. For scale the energy of one rf photon is shown by the arrow enabling the sidebands in the figure to be readily identified. For example, if the line results from either the excited state being dressed upward in energy by one photon, or the ground state downward by one, the sideband line will appear displaced to lower transition energy (to the left) by the length of the arrow.

The data of Fig. 6 was taken with the dispersion being obtained in the conventional manner with Doppler shifts. The true Nuclear Raman Spectroscopy (NRS) is based upon the use of one of these sum or difference frequency sidebands generated by mixing nuclear states as a tunable spectroscopic probe. By varying the frequency of the mixing radiation the energy of the sum frequency line would be swept, just as in the analogous processes implemented in the optical range. While the addition of a tunable sideband to a nuclear source is more instinctively attractive, the complementary experiment with an absorber proves the same principles with less expense.

An extension[12] of the previously described experiment was used to demonstrate the possibility for such Nuclear Raman

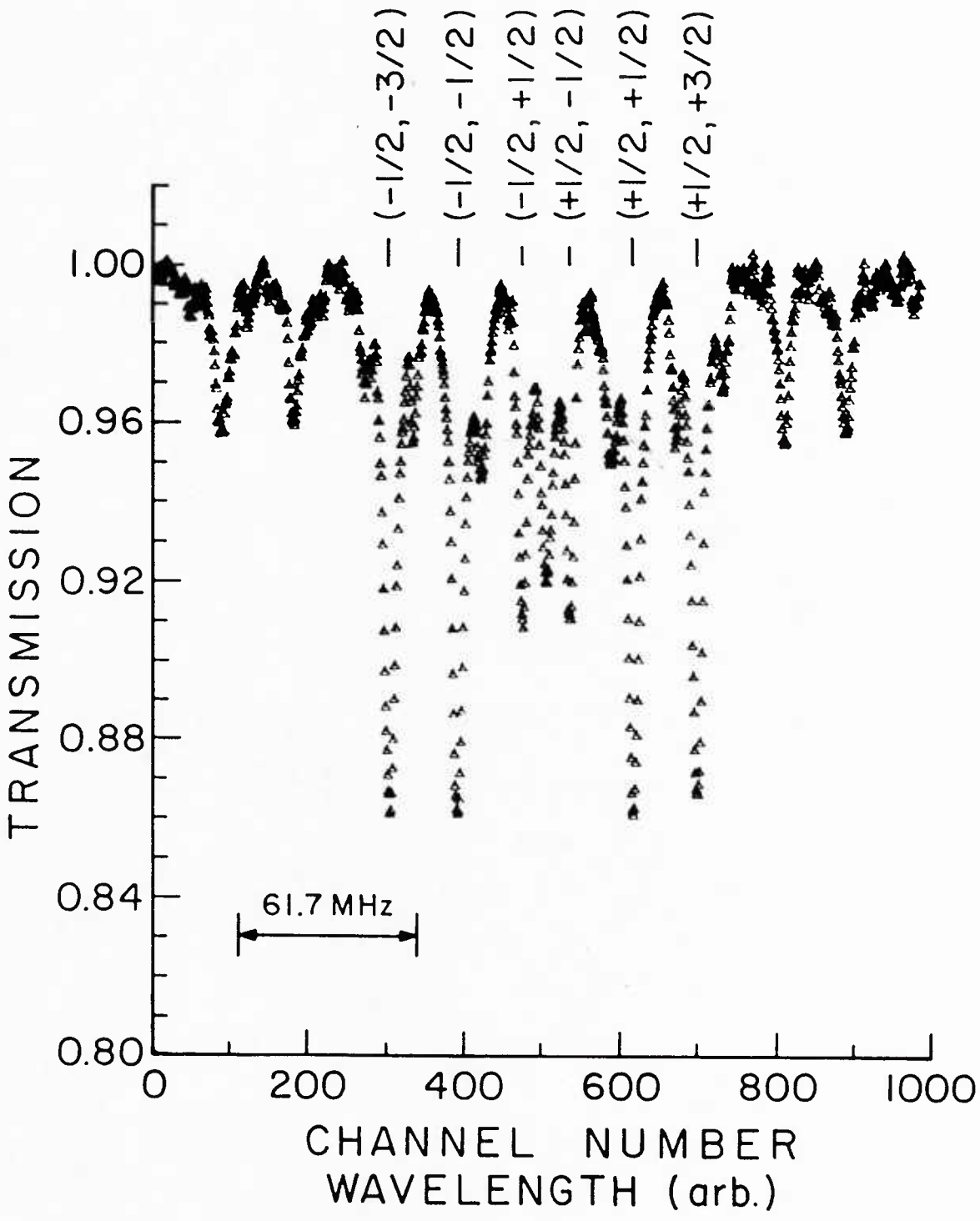


Figure 6

Typical data obtained for pure ^{57}Fe at 10.1 W of radio-frequency power at 61.7 MHz. The parent transitions are identified by (M_i, M_f), the projections of the nuclear spins in the initial and final states, respectively, upon the axis of local magnetization M_s. The change in transition energy resulting from one additional radio-frequency photon is indicated.

Spectroscopy (NRS) with the first prototype system. Figure 7 illustrates the concepts involved. The unsplit source energy corresponded to the wavelength shown in Fig. 7 by the heavy vertical line. At the lower mixing frequency shown in the upper data, the particular feature 5+ lies at longer wavelength than the source, while at higher frequency it lies at a lower value. It can be imagined that with a smooth change of frequencies between the two values, a point would be reached at which the transmission of γ-photons from the source would be suddenly reduced. The realization of this supposition is seen in Fig. 8. In addition to the absorption resonance resulting from the expected, 5+ line, another smaller feature appeared. It corresponded to 3++, the second order sideband to transition #3. It hints at the greater sensitivity of the NRS technique.

In any case, the point of the experiment was not to characterize the energy levels of ^{57}Fe but to demonstrate the effectiveness of this new NRS technique for nuclear spectroscopy in general, based on multiphoton effects. However, with this prototype system, frequencies could be changed only manually with rather elaborate retuning of the radiofrequency system being necessary for the acquisition of each point. Completed during the present contracting period was a full integration of component subassemblies that allows the frequencies to be stepped through a range in response to commands issued from the (Apple) computer controller via the IEEE-488 protocol. Dwell time at each frequency could be set by software at run time. Counts resulting from γ-ray photons detected during the period of

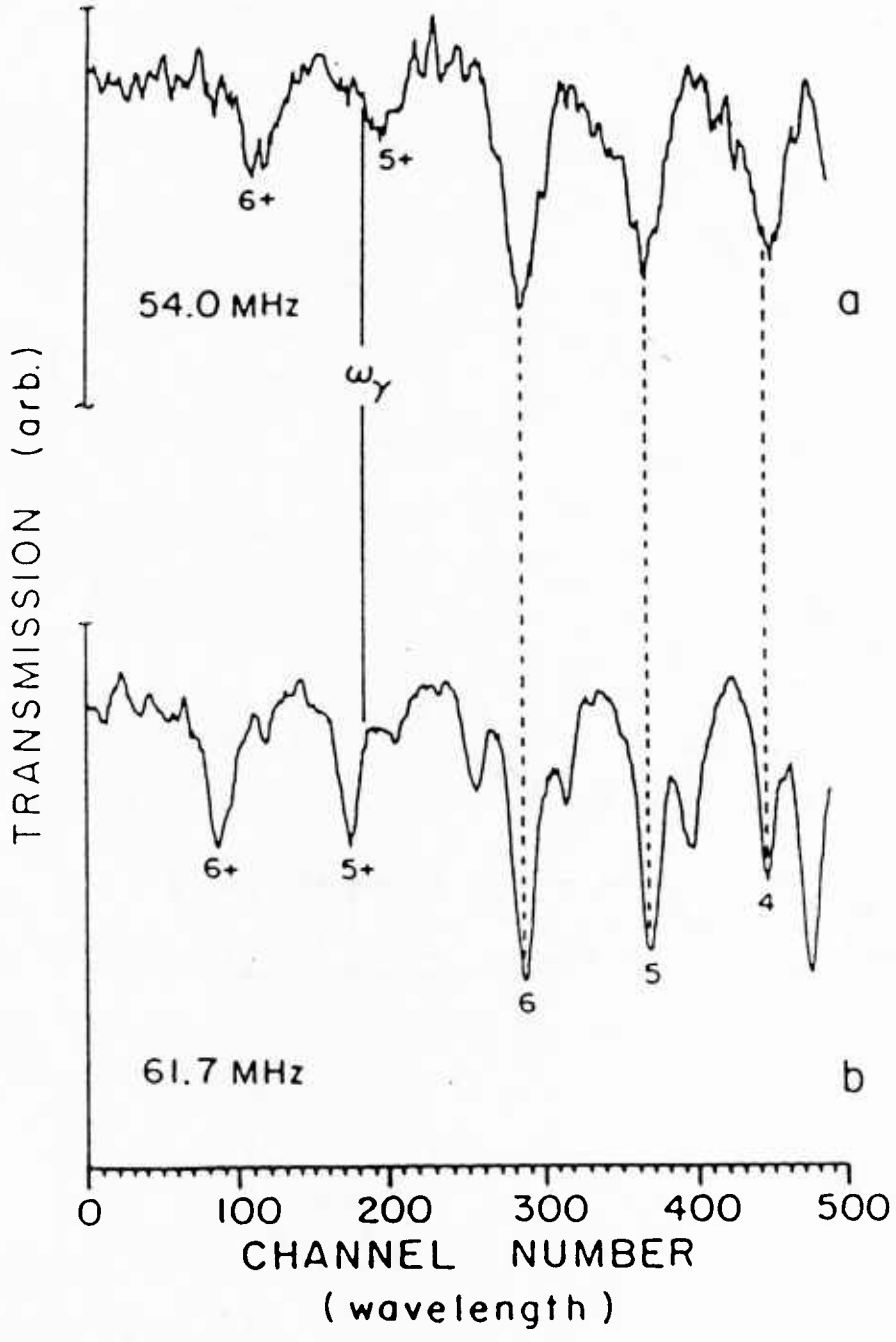


Figure 7

Two spectra that show that the result of increasing ω_{rf} is to push first-order sidebands away from the parents. Source frequency lies at ω_γ.

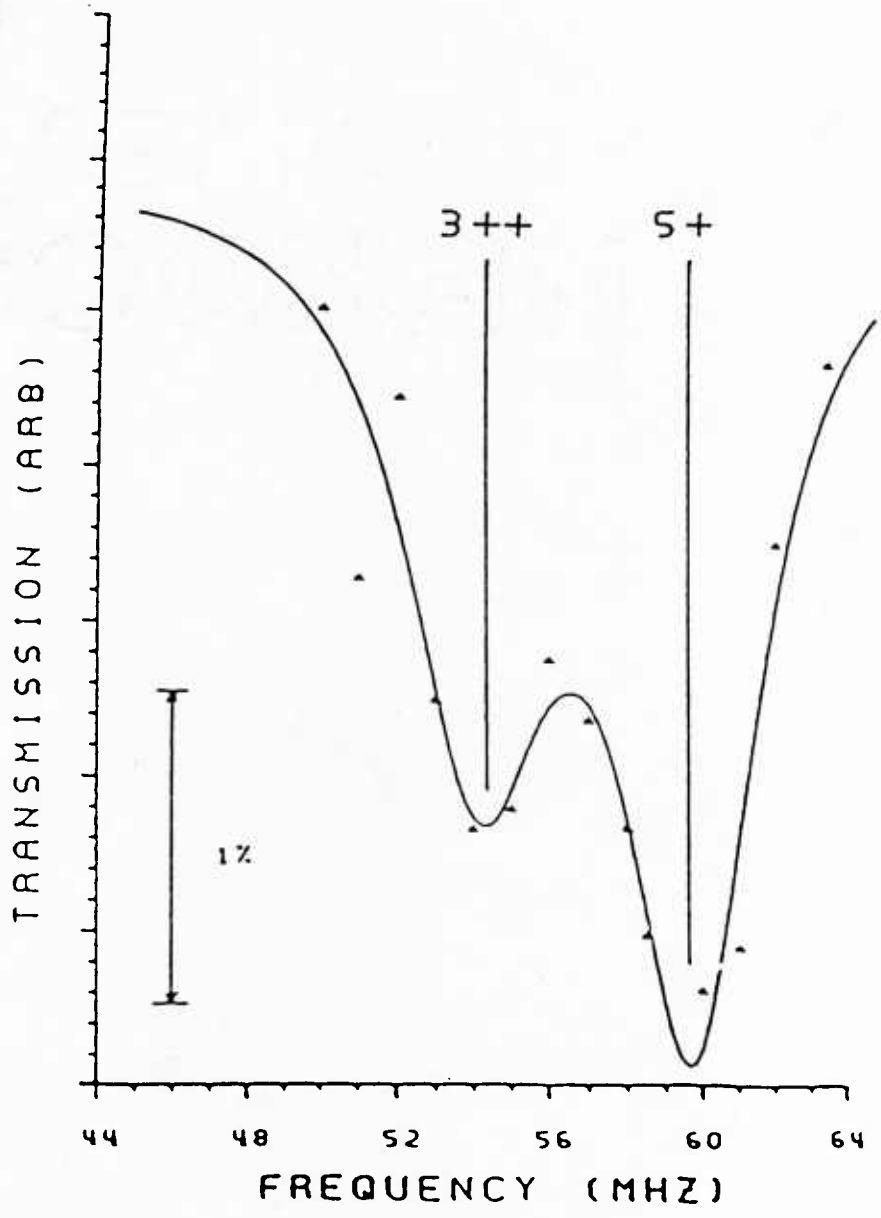


Figure 8

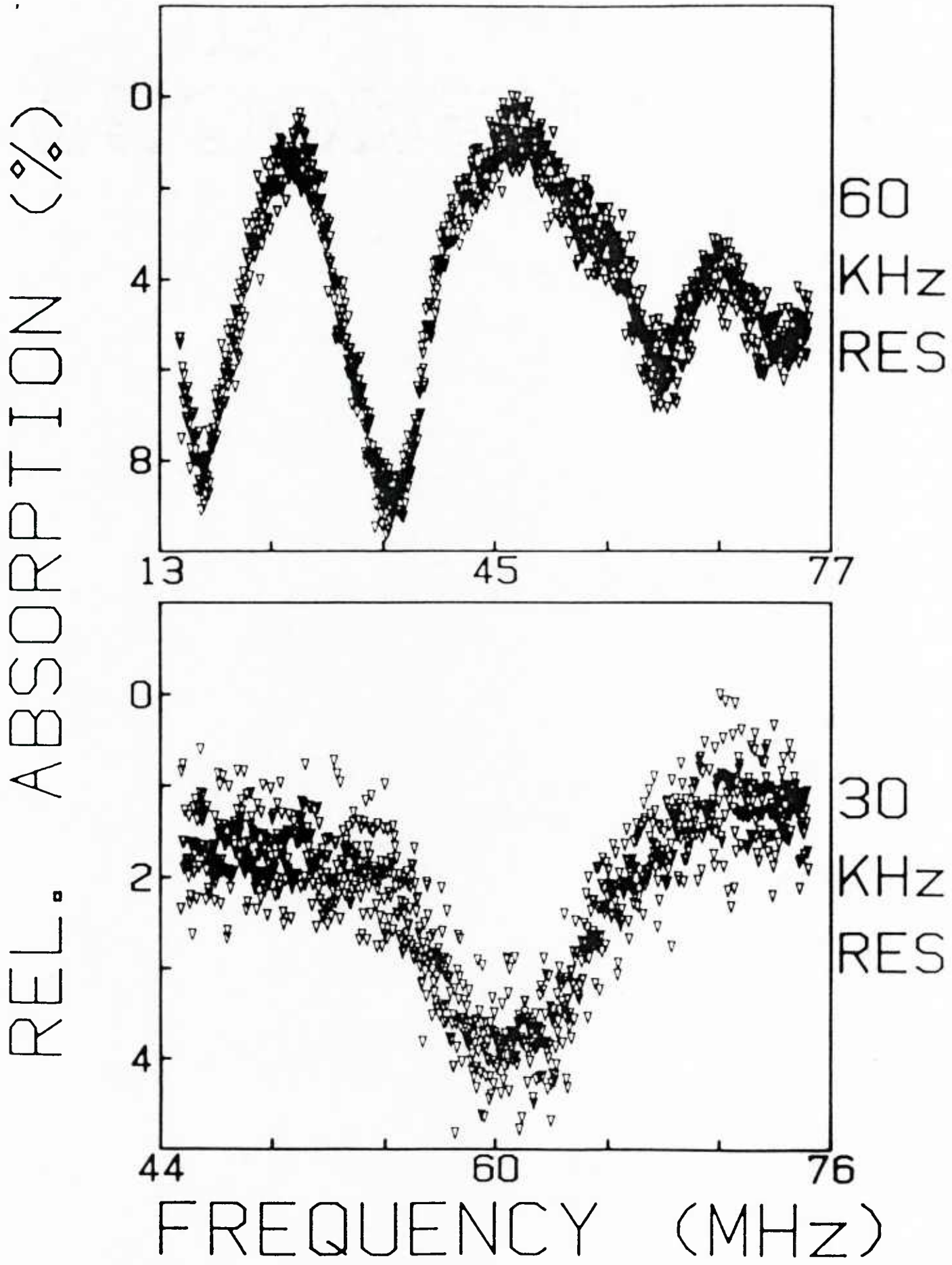
Gamma transmission intensity plotted as a function of rf photon frequency. The larger absorption line corresponds to the first order, sum-frequency sideband of the $|1/2, -1/2\rangle \rightarrow |3/2, -1/2\rangle$ nuclear transition of ^{57}Fe, while the smaller line corresponds to the second-order, sum-frequency sideband of the $|1/2, 1/2\rangle \rightarrow |3/2, -1/2\rangle$ transition.

mixing at a single frequency were stored at addresses identified with that frequency.

Since no mechanical movements or Doppler shifts were involved in any way, instrumental resolution was set by the stability of the frequency synthesized, $\pm$100Hz. However, the transform of the lifetime of the 14.4 keV excited state of ^{57}Fe is 2.3 MHz so no detail can be expected on a scale significantly smaller than MHz. Figure 9 presents the first NRS spectrum ever obtained that is densely packed with observations at contiguous frequency intervals. Instrumental resolution of both 60 and 30 kHz are shown.

An unexpected richness of structure is shown in Fig. 9. The feature to the right of center, magnified in the higher resolution scan is the superposition of the (-1/2, -3/2) minus one photon sideband with the (+1/2, +3/2) plus one photon sideband, as expected. These two absorption peaks are not precisely coincident, rather being displaced by a frequency, ν_i such that $h\nu_i$ is the chemical shift of energies between the radioactive source and absorber. The appearance of two peaks is clear in the high-resolution version and could be fit to two lineshape functions from which the chemical shift could be extracted.

Some of the other features can be interpreted as expected sidebands but some are more difficult to identify. While those latter examples reproduce during remeasurement of the spectrum, their relative intensities seem quite sensitive to surface conditions of the absorber material and may reflect further shifts in energy caused by the proximity of a surface. Much more work is needed for an unequivocal interpretation. Nevertheless,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FREQUENCY (MHz)

Figure 9

such data attest to the extraordinary power and resolution of the NRS system.

SIGNIFICANCE

The achievements of this contracted work are very significant to the critical path for development of a gamma-ray laser. A gamma-ray laser is feasible if the needed sequence of energy levels can be found in some real nucleus. Theory suffices to identify 29 prime candidates among the 1886 distinguishable nuclear materials, but further screening to eliminate inutile members of this prime set of materials cannot be done with conventional technology.

Described in this report are the successful demonstrations of two new devices which can be scaled to a capacity able to evaluate the 29 candidates in a realistic time frame. One is the flash x-ray device needed to mount the nuclear analog of optical double resonance measurements to evaluate pumping efficiencies and requirements. The ultimate signal which can be made available to provide a basis for judgment of the merits of a particular candidate material will be directly proportional to the total keV/keV emitted by the x-ray source per hour of laboratory time. The table top device reported here has already achieved over 10^{19} keV/keV per hour in early tests. It was designed to represent 1/10 scale of a single module of the ultimate device which would be used in an array of 16 modules for the screening of candidates. Thus it is entirely reasonable to project an average spectral power of 2×10^{21} keV/keV per hour in the range of photon energies from a few to 115 keV.

The other device reported here is the Nuclear Raman

Spectrometer bringing the combination of extended resolution and extended tuning range needed for the identification of nuclear states useful in dressing isomeric levels. To dress an isomeric state requires a certain arrangement of nuclear levels that would make them indetectable to conventional techniques of nuclear spectroscopy. Our method of NRS is the only means found to date that can be used to search for this combination among the 29 best candidates. The successes of the new NRS apparatus for nuclear spectroscopy indicate that a much higher resolution, by perhaps six orders of magnitude, can be achieved through a reasonable upgrade of the apparatus. If the range of tunability does extend to the ferromagnetic spin resonance (FSR) frequency, then it will be possible to construct a swept frequency device capable of continuously tuning over a range of 10^{11} linewidths, an enormous improvement in the state-of-the-art of nuclear spectroscopy.

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